

Accretion onto Sgr A*

This is a false-color astronomical image of the central region of the Milky Way. The image shows a large, diffuse, orange-red cloud of gas and dust, which is the accretion disk or inflow of material towards the supermassive black hole Sgr A*. Several bright, point-like sources of light are visible, representing individual stars. The most prominent one is at the center, where the black hole is located. Other stars are scattered throughout the field of view, some appearing as sharp points and others as slightly blurred disks. The background is black, representing the deep space beyond the galactic plane.

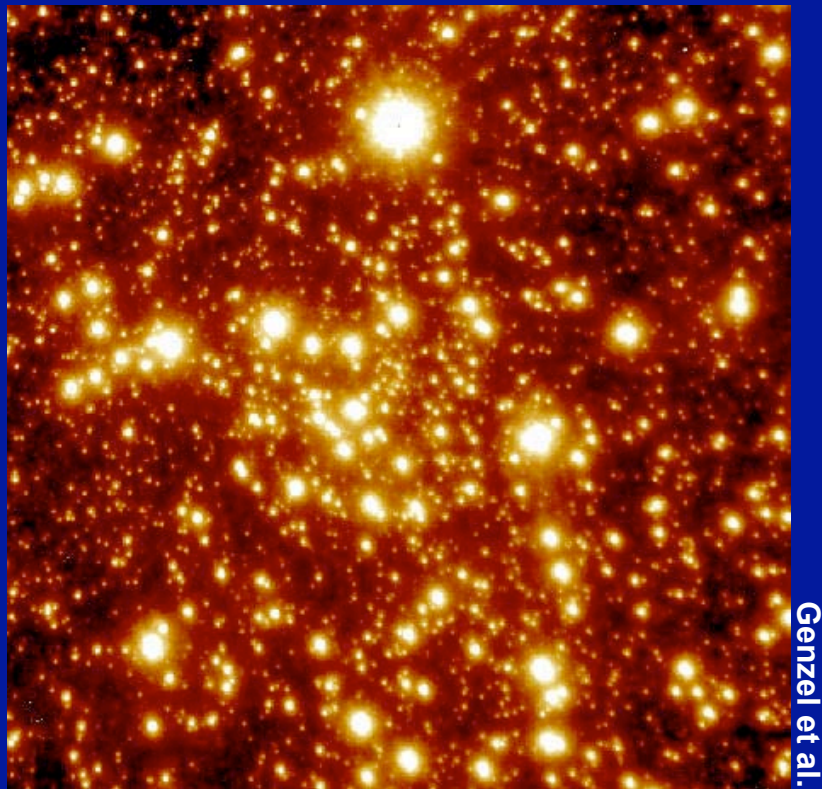
Eliot Quataert
(UC Berkeley)

Outline

- Radiatively Inefficient Accretion Models for Sgr A*
 - Boundary Conditions at Large Radii
 - Physical Conditions at Small Radii
 - Interpretation of the Observed Spectrum
- Gamma-rays from Sgr A* and the Central \sim Pc

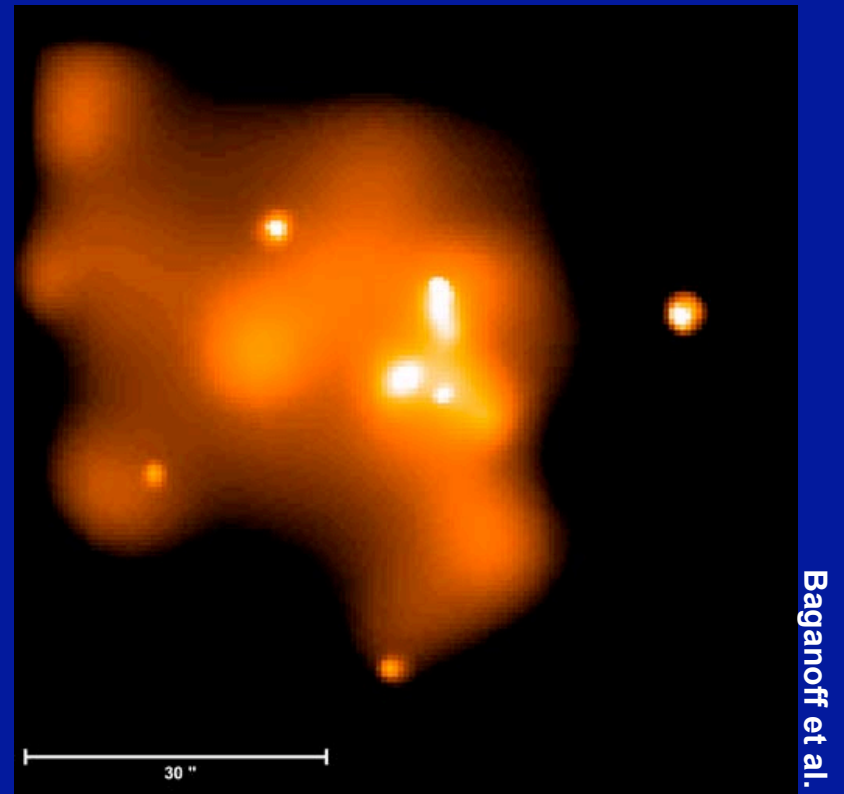
Fuel Supply

IR (VLT) image of central \sim pc



Young cluster of massive stars
in the central \sim pc loses \sim
 $10^{-3} M_{\odot} \text{ yr}^{-1}$ ($\approx 2-10''$ from BH)
 $1'' = 0.04 \text{ pc} \approx 10^5 R_s$ @ GC

Chandra image of central $\sim 3 \text{ pc}$



Hot x-ray emitting gas
produced via shocked
stellar winds
($n \sim 10-100 \text{ cm}^{-3}$; $T \sim \text{keV}$)

Gravitational Capture of Ambient Gas (Bondi Accretion)

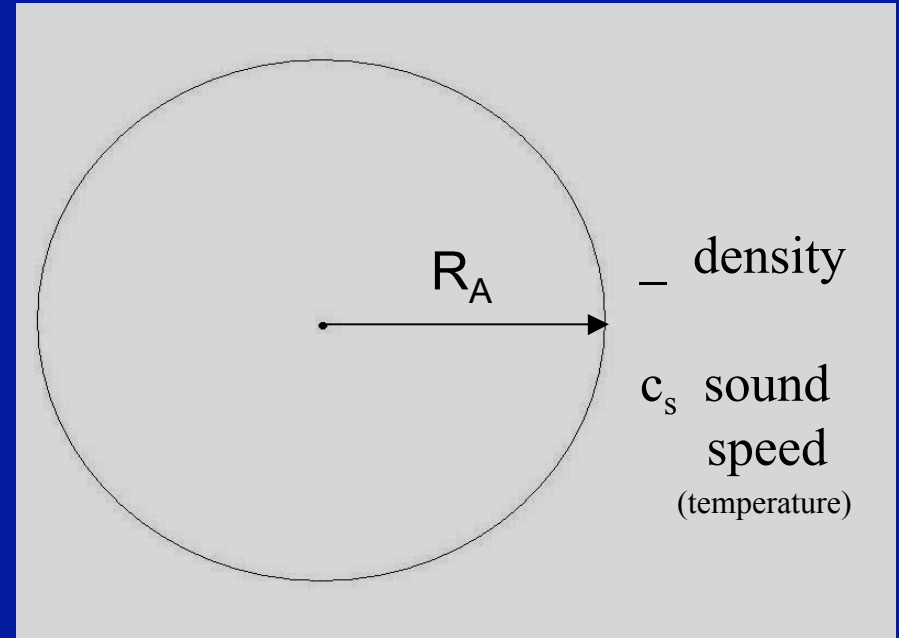
- BH surrounded by gas with density ρ and sound speed c_s

$$R_A \approx \frac{GM}{c_s^2} \gg R_S$$

$$\dot{M}_{Bondi} \approx 4\pi R_A^2 \rho c_s$$

Estimates Give:
 $(R_A \approx 10^5 R_S \approx 1'')$

$$\dot{M} \approx 10^{-5} M_8 \text{ yr}^{-1}$$

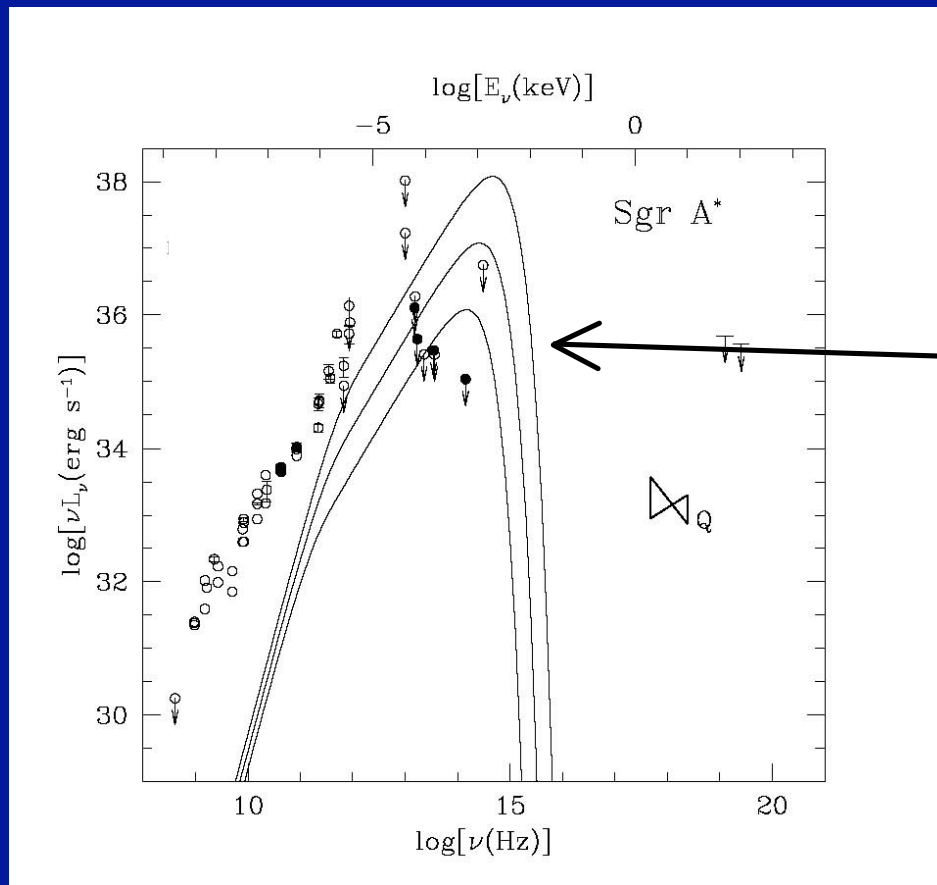


R_A determines the BHs gravitational sphere of influence

3D Hydro Simulations yield similar accretion rates and suggest the flow circularizes at $\sim 10^3\text{-}10^4 R_S$
 (Coker & Melia 1997; Cuadra et al. 2005)

Arguments Against Accretion at smaller radii proceeding via an Optically Thick, Geometrically Thin Disk, as in Luminous AGN

$$L \sim 10^{36} \text{ ergs s}^{-1} \sim 10^{29} \text{ W} \sim 100 L_{\odot} \sim 10^{-9} L_{\text{EDD}}$$



1. inferred low efficiency

$$L_{\text{obs}} \approx 10^{-6} \dot{M}_{\text{Bondi}} c^2$$

2. where is the expected blackbody emission?

$$\dot{M}_{\text{disk}} < 10^{-10} M_8 \text{ yr}^{-1}$$

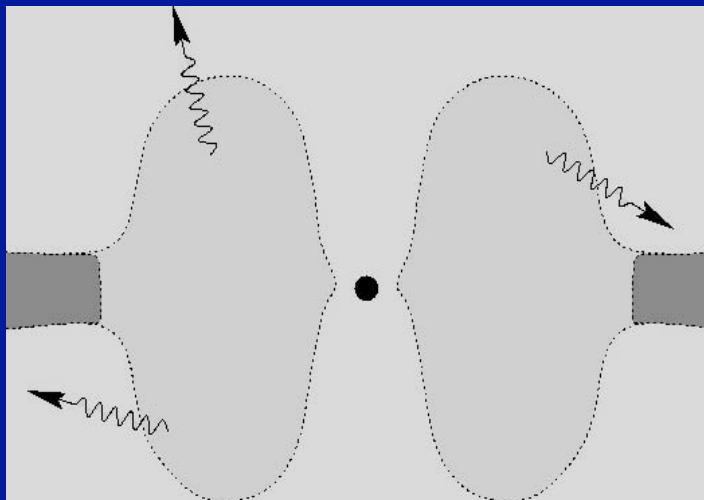
3. observed gas on $\sim 1''$ scales is primarily hot & spherical, with $t_{\text{cool}} \gg t_{\text{flow}}$

4. absence of stellar eclipses argues against $\tau \gg 1$ disk
(Cuadra et al. 2003)

Radiatively Inefficient Accretion Flows

(e.g., Ichimaru 1977; Rees et al. 1984; Narayan & Yi 1994)

- At low densities (low accretion rates), cooling is inefficient
- Grav. Pot. Energy \Rightarrow Heat; **not radiated** $L \ll 0.1 \dot{M} c^2$
- ♣ \Rightarrow very hot (collisionless) plasma: $T \sim GMm_p/3R_s \sim 10^{12}$ K



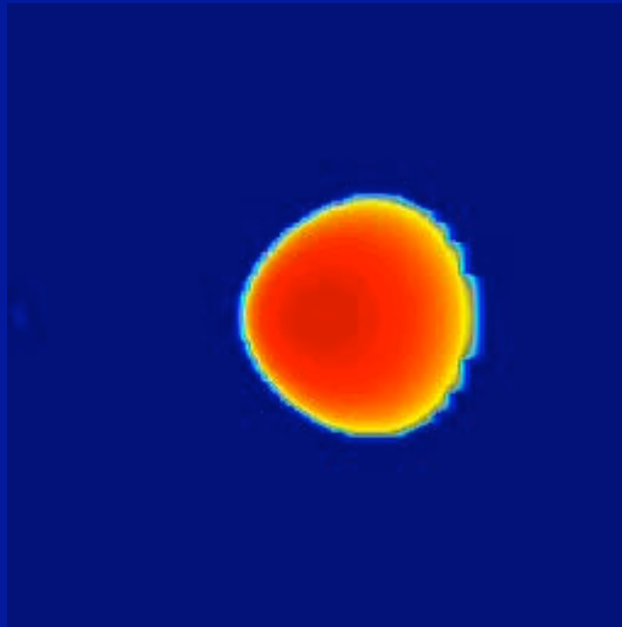
$$T_p \sim 10^{12} \text{ K}$$
$$T_e \sim 10^{11} \text{ K}$$

(+ nonthermal tail)

Rotating w/ $\Omega \sim \Omega_K$ but
geometrically “thick”

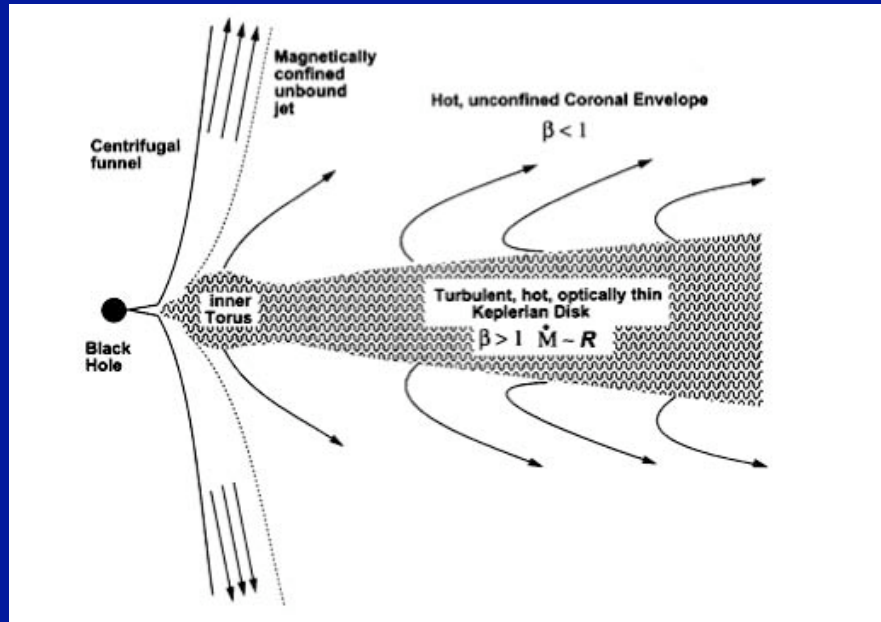
Global Accretion Simulations

John Hawley



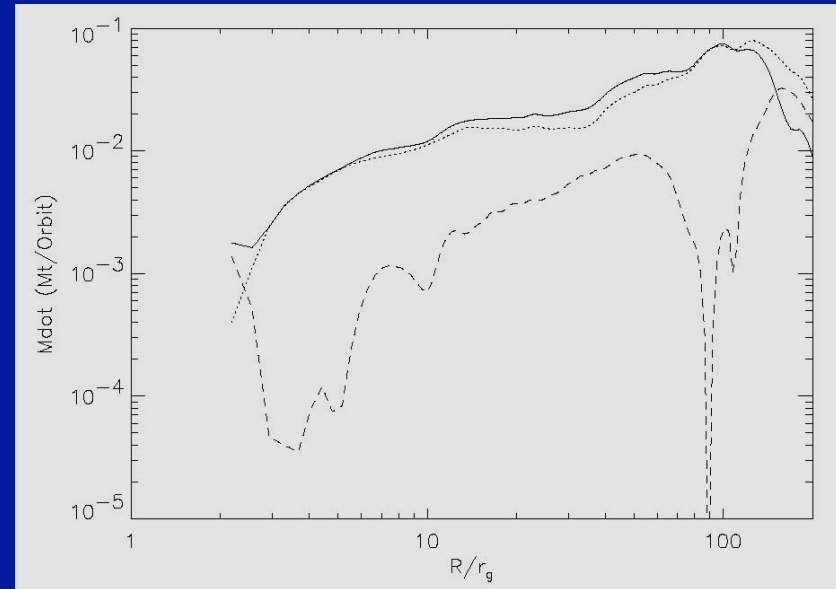
Accretion flow is time-dependent, with large fluctuations in density, temperature, magnetic field strength, etc.

Global Accretion Simulations




Hawley & Balbus 2002

Accretion Rate




(Stone & Pringle 2001; Hawley & Balbus 2002; Igumenshchev et al. 2003)

Simulations indicate that very little of the available mass accretes onto the central object (both MHD & hydro sims w/ α viscosity)


$$\dot{M}_{BH} \sim \dot{M}_{Bondi} \frac{R_{in}}{R_{circ}} \sim 10^{-3} \dot{M}_{Bondi} \sim 10^{-8} M_8 \text{ yr}^{-1}$$

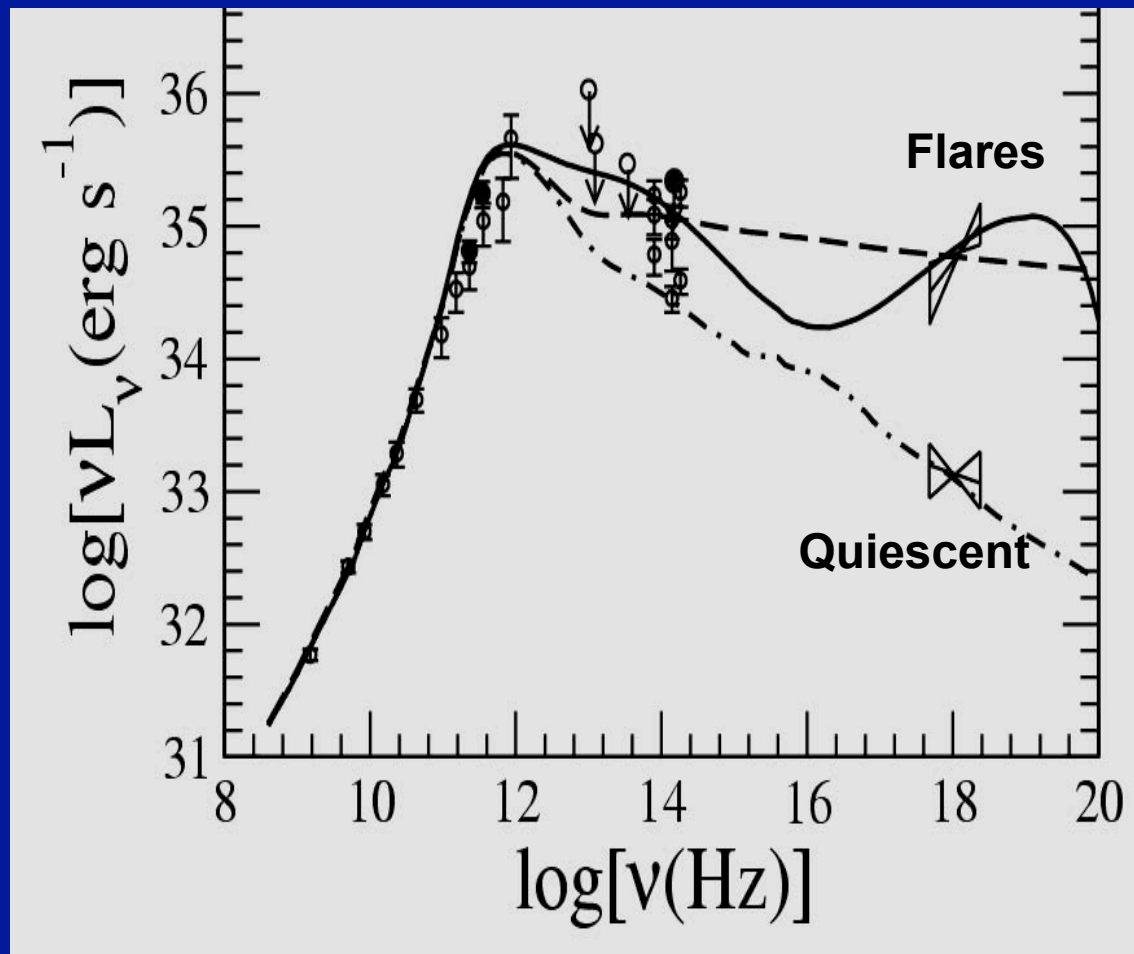
- Low accretion rate strongly suggested by linear polarization in the mm w/ $RM < 10^6 \text{ rad m}^{-2}$



physical
conditions
near BH

$$T_p \sim 100 \text{ MeV} > T_e \sim 20 \text{ MeV}$$
$$n_e \sim 10^{6-7} \text{ cm}^{-3} \quad B \sim 30 \text{ G}$$

Modeling the Spectrum of Sgr A*



Yuan et al. 2004

mm: thermal synchrotron
from $\sim \text{few } R_s$

IR: nonthermal synch
($\sim \text{few-10 \%}$ of electrons
in a power law tail)

Quiescent X-rays: thermal
emission from $\sim R_{\text{Bondi}}$

X-ray Flares: synchrotron &
SSC may both be present

IR & X-ray flares from
transiently accelerated
electrons in inner $\sim \text{few-10 } R_s$

High Energy Gamma-rays from Sgr A*?

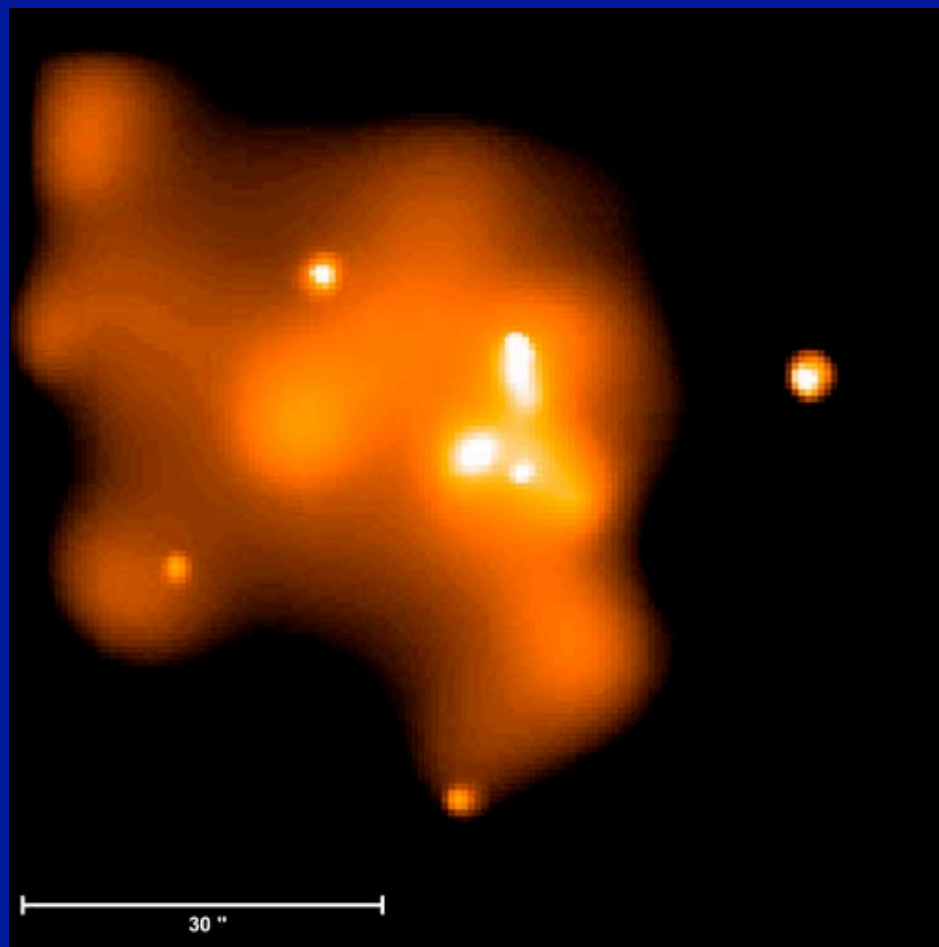
■ π^0 decay: $L_\gamma \approx 10^{33} n_7^2 \left(\frac{T_p}{100 \text{ MeV}} \right)^3 \text{ ergs s}^{-1}$

– low accretion rate \Rightarrow low density \Rightarrow low flux from π^0 decay

■ IC from rel. e-s: uncertain, but ...

- $U_B \sim 10\text{-}100 U_{\text{ph}}$: electrons primarily lose energy to synchrotron not IC
- IR spectra generally steep, suggesting inefficient high γ accelerator

Shocked Stellar Winds: A Better Particle Accelerator?



$\sim 10^{-3} M_{\odot} \text{ yr}^{-1}$ lost in the central 0.5 pc

Wind energy thermalized via
collisionless shocks (as in SN, GRBs ...)

$$\dot{E}_{shocks} \approx 0.5 \dot{M}_w V_w^2 \approx 3 \cdot 10^{38} \dot{M}_{-3} V_8^2 \text{ ergs s}^{-1}$$

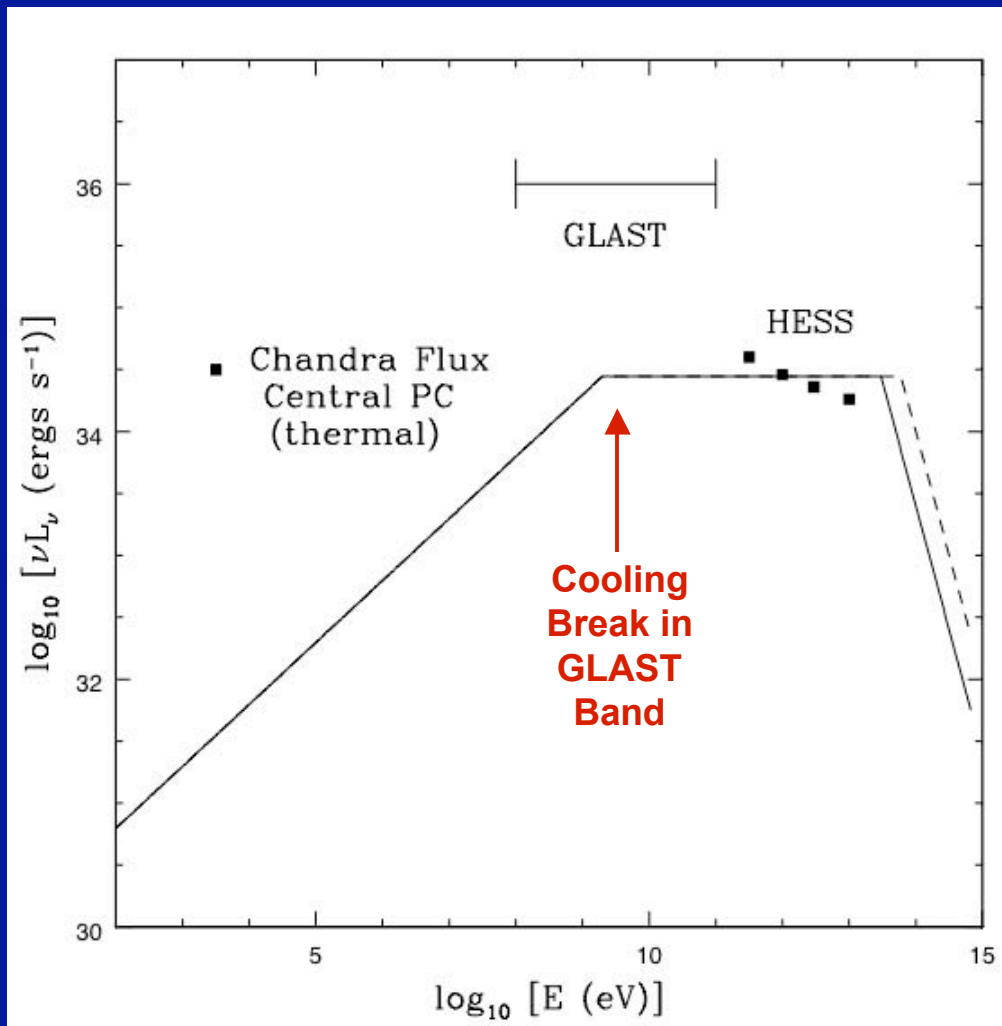
$$> \dot{E}_{acc} \approx 0.1 \dot{M}_{BH} c^2 \approx 5 \cdot 10^{37} \dot{M}_{-8} \text{ ergs s}^{-1}$$

$\sim 10\%$ of energy to high γ protons

$\sim 1\%$ of energy to high γ electrons

$$n(\gamma) \propto \gamma^{-2}$$

TEV HESS Source & GLAST Counterpart: IC on the Stellar Radiation Field



EQ & Avi Loeb

0.3% of shock energy into rel.
electrons w/ $n(\gamma) \propto \gamma^{-2}$

Central PC

$$U_{\text{ph}} \sim 10^{-7} \text{ ergs cm}^{-3} \text{ in UV}$$

$$U_{\text{ph}} \sim 10^{-8} \text{ ergs cm}^{-3} \text{ in FIR}$$

$$t_{\text{cool}} < t_{\text{esc}} \sim R/V_{\text{wind}} \text{ for } \gamma > 10^4$$

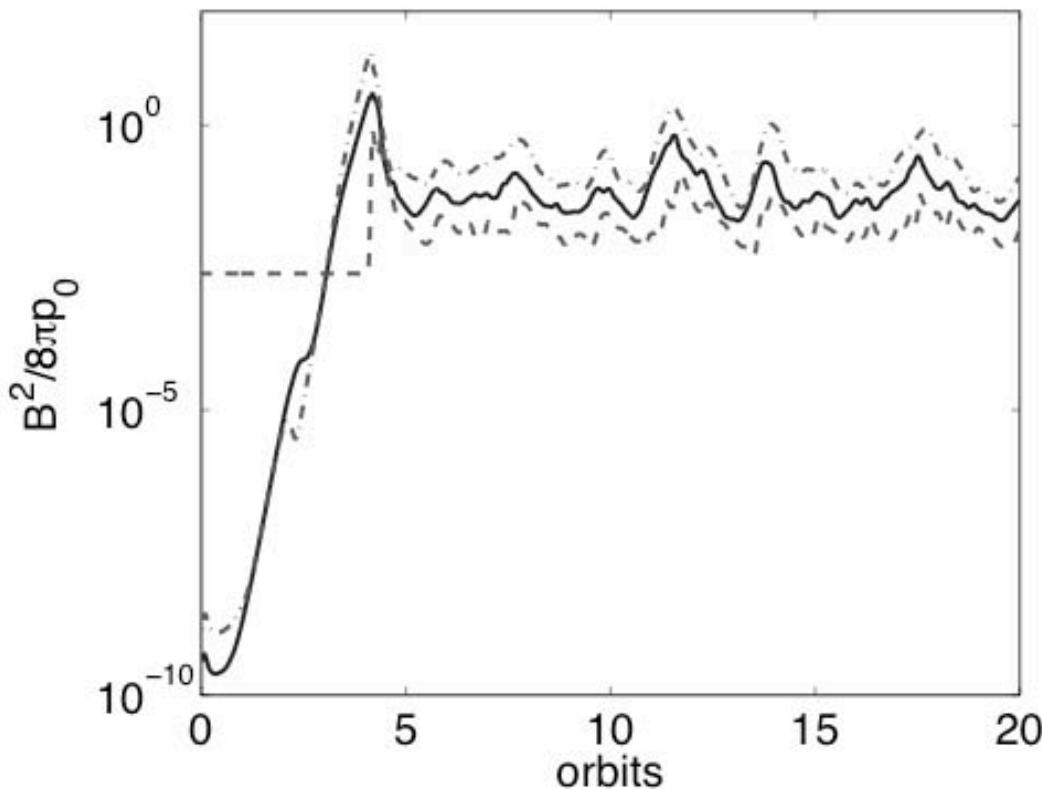
Cooling Break

$$E_b \approx 2 \left(\frac{R_{0.5} V_8}{L_{41}} \right)^2 \left(\frac{E_{\text{ph}}}{5 \text{ eV}} \right) \text{ GeV}$$

Summary

- Accretion of Gas onto Sgr A* occurs via a hot low density radiatively inefficient accretion flow
 - true for most BHs, most of the time
- Highly variable emission from IR-X-rays signature of magnetized, turbulence accretion flow in inner few R_S
 - Efficiency of gamma-ray production uncertain (probably low)
- Electrons accelerated in stellar wind shocks in the central \sim parsec can account for HESS TeV source: predicts \sim GeV cooling break in GLAST band

Local (Shearing Box) Simulations of the MRI in a Collisionless Plasma



**Saturation Levels Similar
to MHD Simulations**

**Angular Momentum
Transport via
Anisotropic Pressure
in addition to
Maxwell Stress**

**Local Rate of
Angular Momentum
Transport Enhanced
(by factor ~ 2)**

Sharma, Hammett, Quataert, & Stone, 2005

The Bondi Numbers

$$\dot{M}_{Bondi} \approx 4\pi R_A^2 \rho c_s \big|_{R \approx R_A}$$

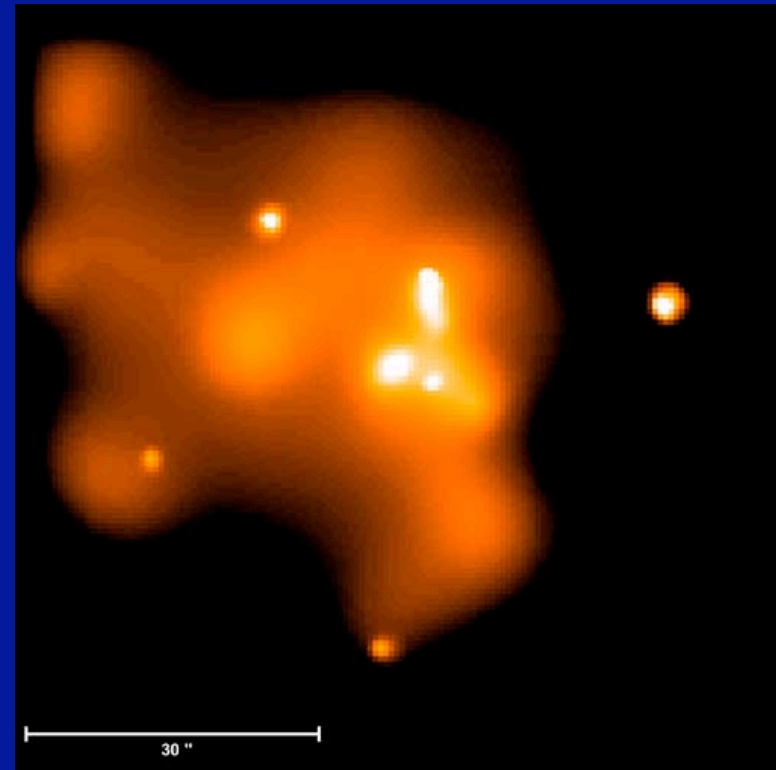
$$R_A \approx \frac{GM}{c_s^2} \approx 1''$$

$$\dot{M}_{Bondi} \approx 10^{-5} M_8 \text{ yr}^{-1}$$

**3D Hydro Simulations yield
similar accretion rates
and suggest the flow
circularizes at $\sim 10^3\text{-}10^4 R_S$**

(Coker & Melia 1997; Cuadra et al. 2005)

$$1'' \approx 0.04 \text{ pc} \approx 10^5 R_S \approx R_A$$



Hot $n(10'') \approx 20 \text{ cm}^{-3}$ $T(10'') \approx 1 \text{ keV}$
Gas $n(1'') \approx 100 \text{ cm}^{-3}$ $T(1'') \approx 2 \text{ keV}$